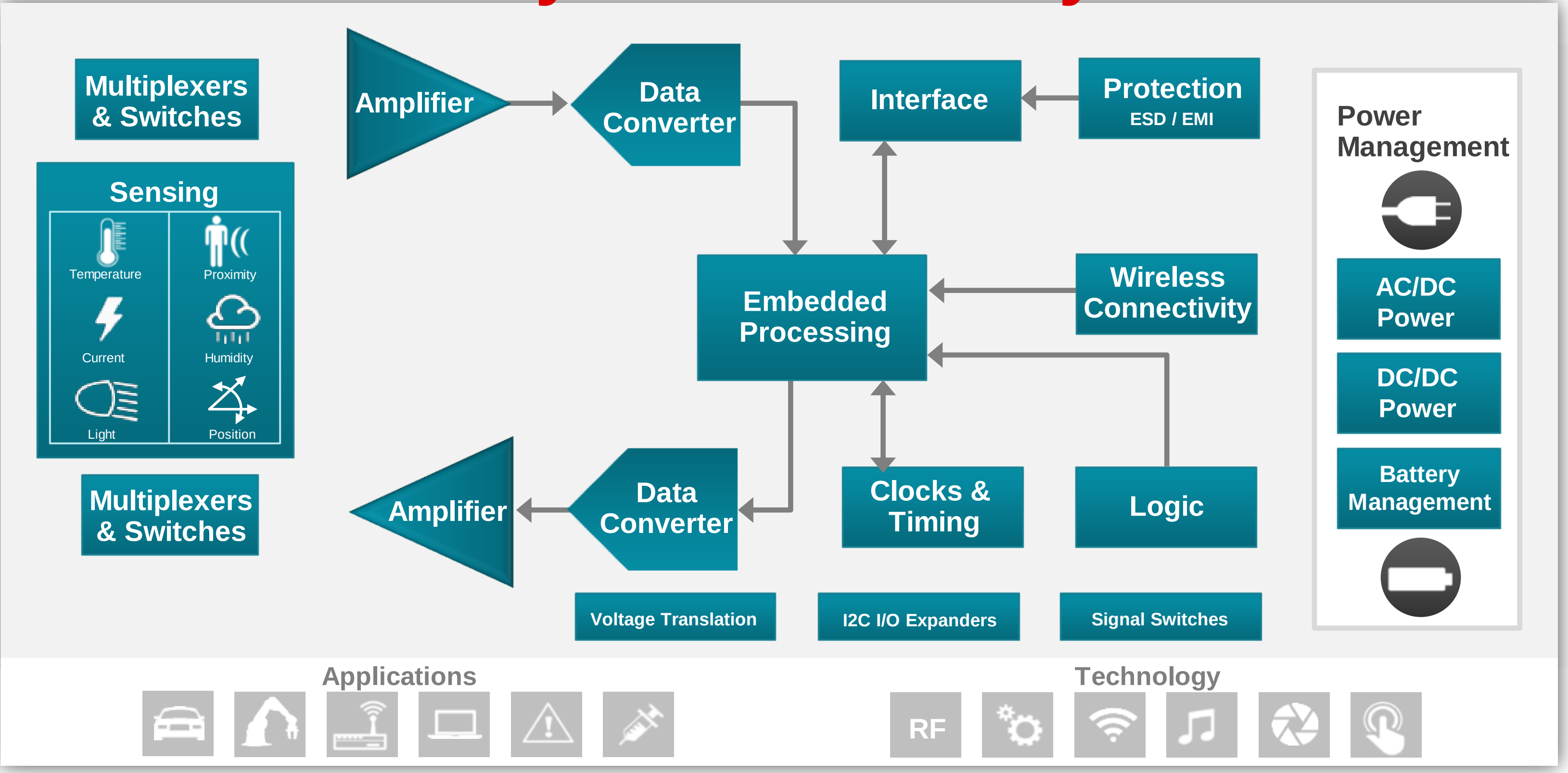
Accelerating Automotive

- 48V System in EV/HEV

Texas Instruments

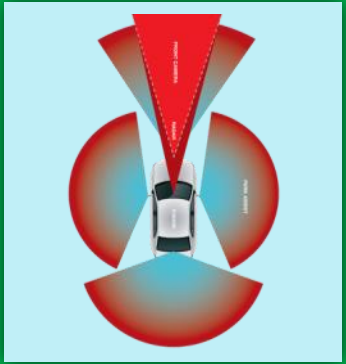
Zhicheng Yao

TI Analog and Embedded Processing Technologies at The Heart of Any Automotive System



TI Innovation Focuses on Four Automotive Sectors

Advanced driver assistance systems



Adaptive cruise control
Night vision
Blindspot detection
Lane departure warning

Safer driving environment

Infotainment & cluster

Entertainment system
Head-up display
Navigation system
eCall

Connected driving experience

Body electronics & lighting

Security system
Seat position control
Remote keyless entry
Lighting

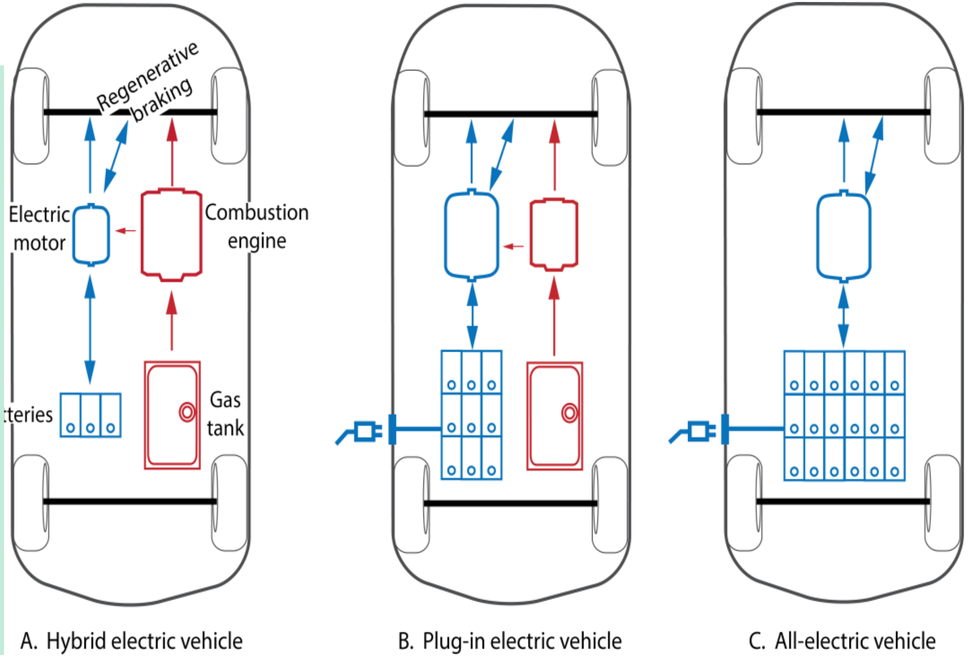
Differentiation in lighting and body electronics

Hybrid/electric and powertrain systems

Automatic start/stop
Battery management
Electric power steering
Engine and transmission control

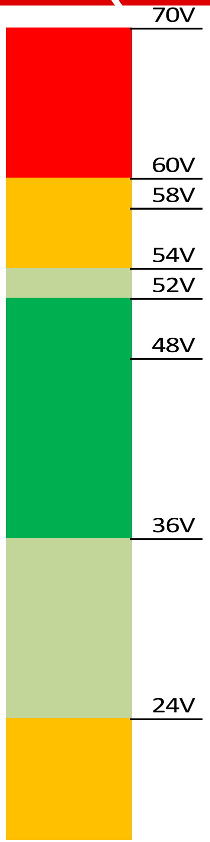
Electrification of vehicles

EV/HEV Definitions

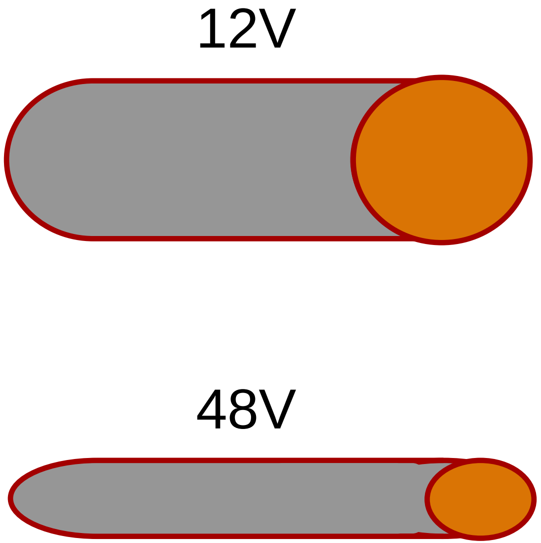


Why high voltage? Why 48V? What's BAT history?

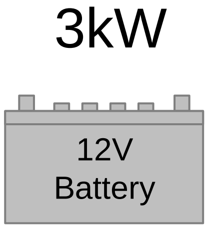
BAT 6V (1918) › 12V (1950) › 48V (2011)

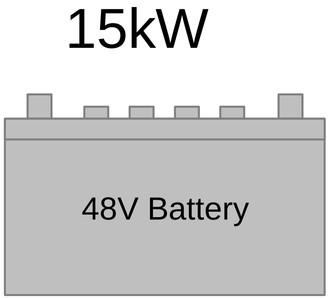


Cable Thickness



Max. Power

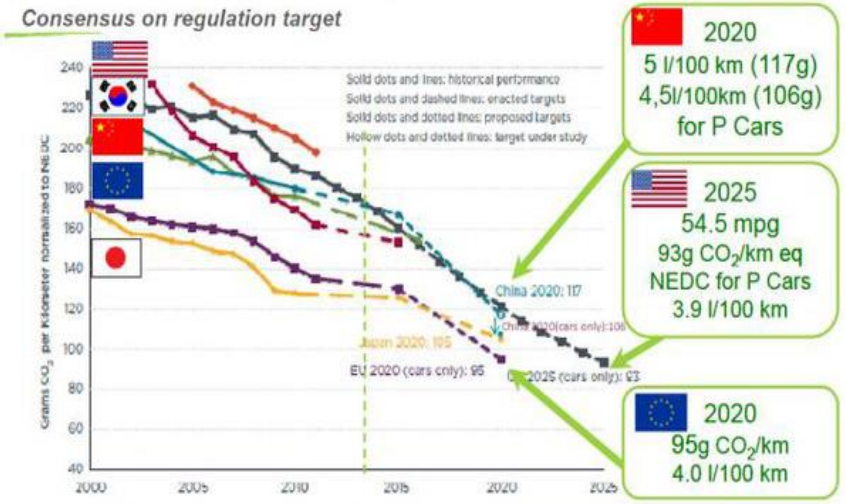


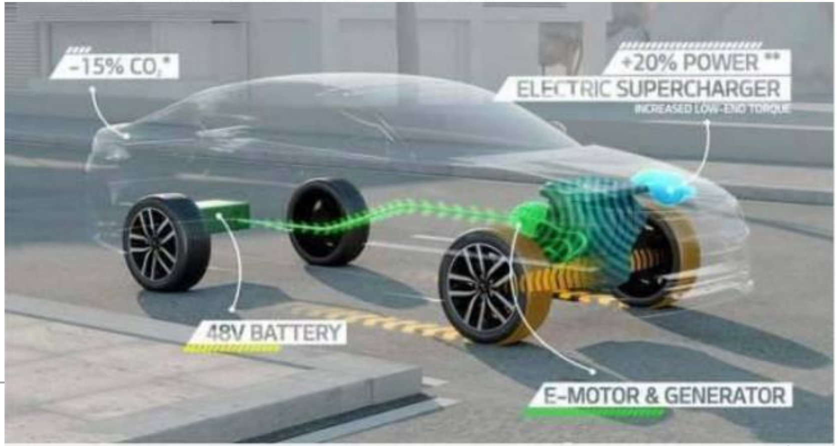


(Source: LV148, 15th "Automobil Elektronik Kongress" in Ludwigsburg 2011 Germany)

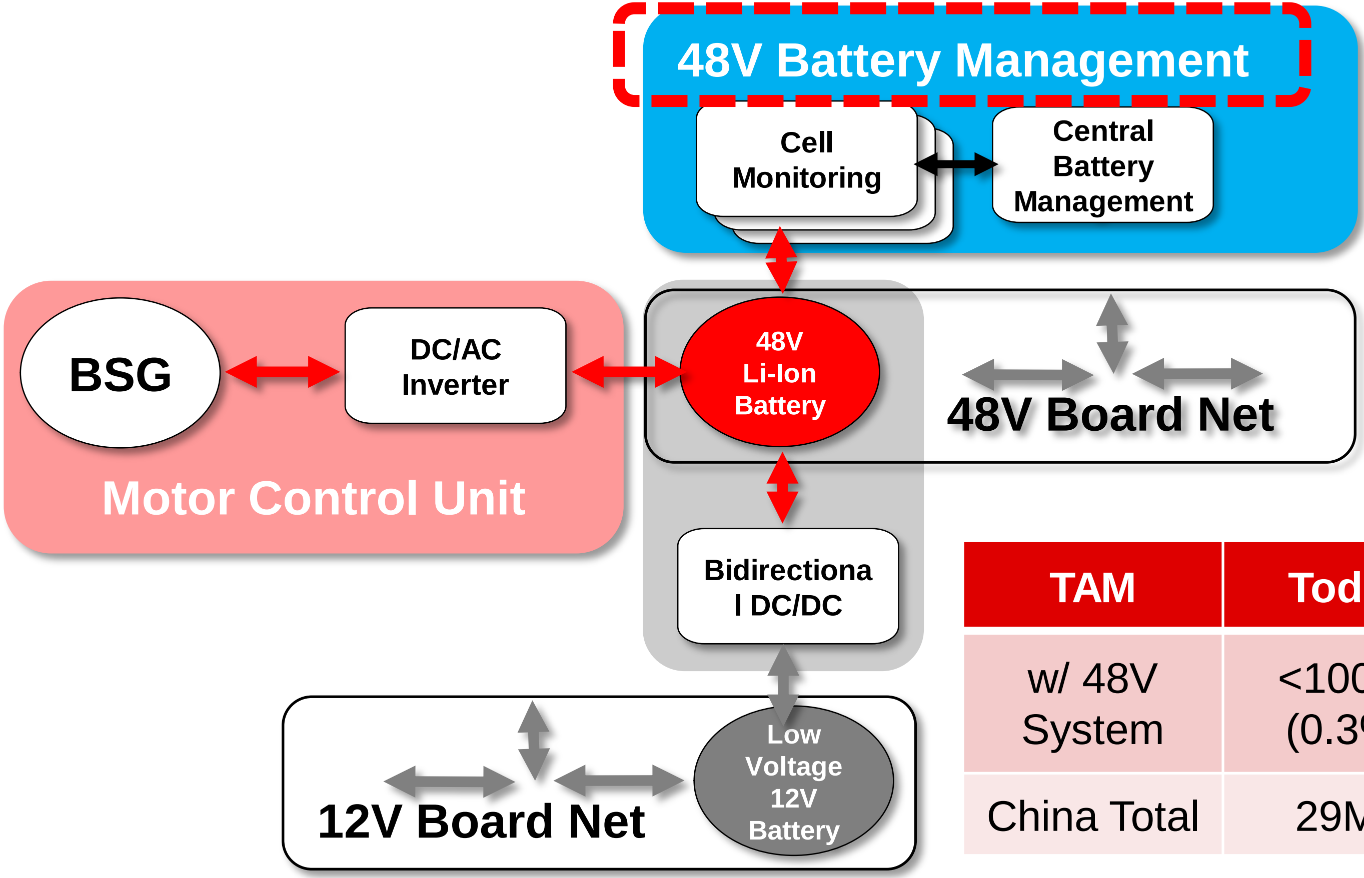
Market Trends Driving 48V in Automotive

- Fuel economy
  - Enhancing Start-Stop operation faster
  - Energy recuperation more efficiency during braking
- CO2 reduction
  - Government regulations demanding CO2 emissions to decline sharply
- Higher power consumption
  - Unable to get power from the 12V battery
- Comfort during Start/Stop functions
  - A/C compressor continuous operation



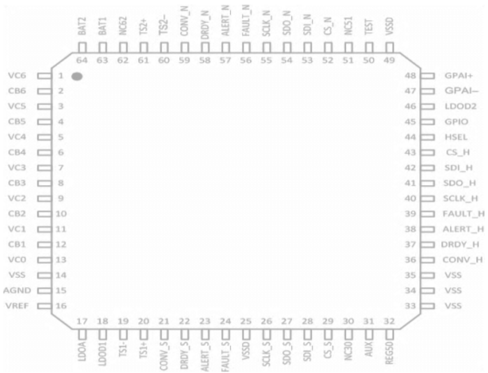


48V Architecture Overview



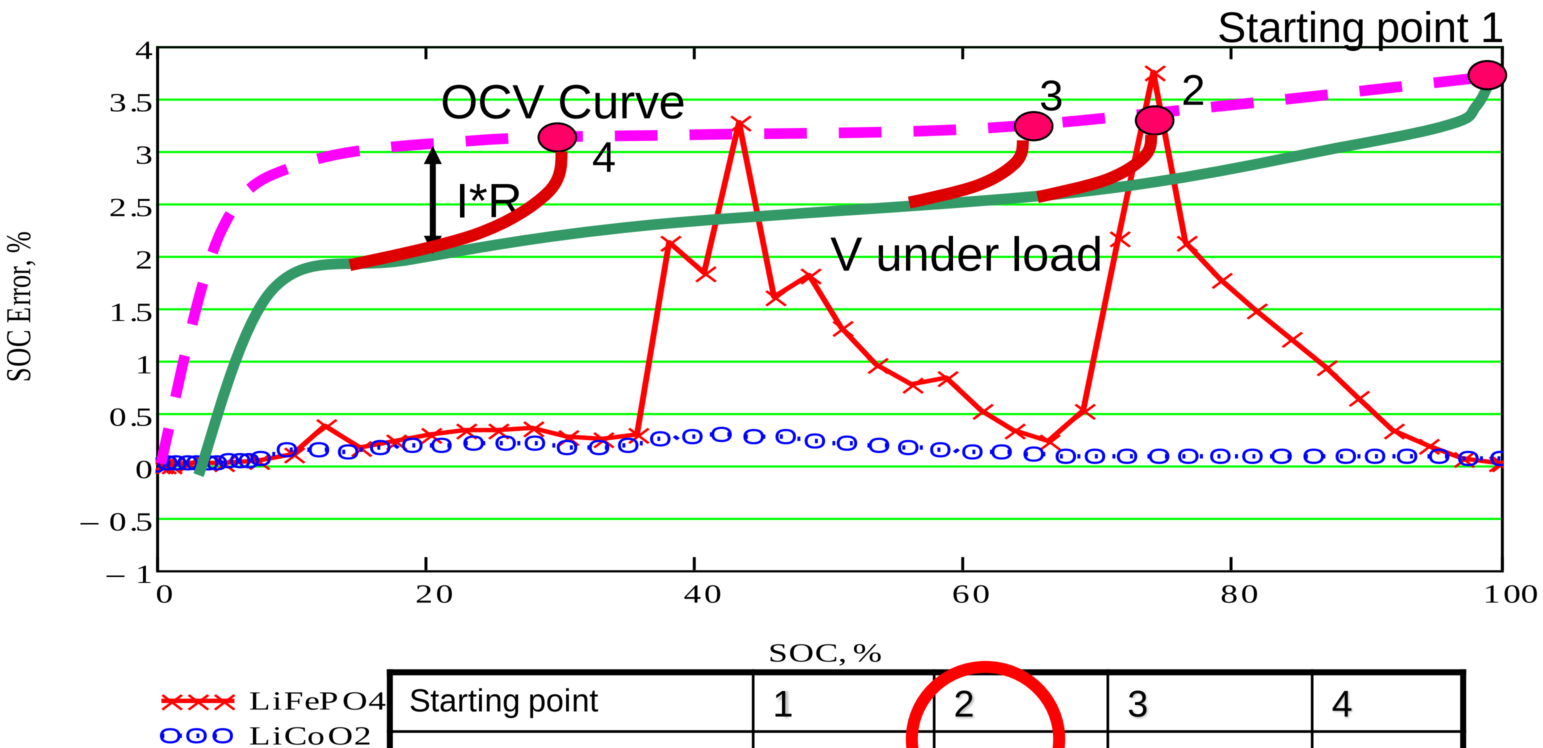
TAM	Today	2025
w/ 48V System	<100ku (0.3%)	28Mu(80%)
China Total	29Mu	35Mu

48V BMS IC Selection



- Semiconductor Selection:
  - ✓ Automotive qualified (Q-100 Grade 1 or 2) part
  - ✓ Vendor experience in BMS and Automotive markets
  - ✓ Accuracy (over temperature range)
  - ✓ Strong Built-in Self Test, ASIL-C/D Conformance
  - ✓ High-speed communications, reliability of data
  - ✓ Immunity to ESD, EMC (RFI, conducted), BCI
  - ✓ Cell temperature monitoring channels
  - ✓ Balancing support – passive
  - ✓ Low supply current, especially in Shutdown mode

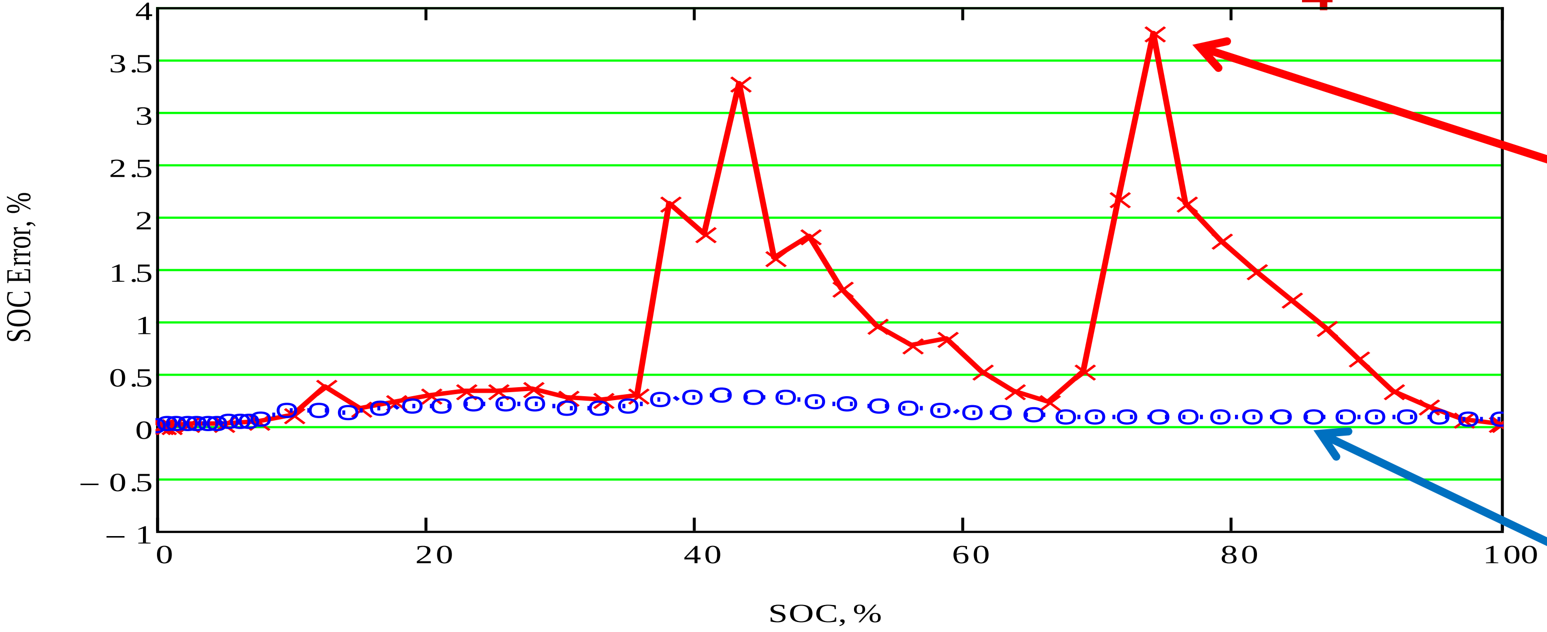
Direct Voltage Correlation Error for $LiFePO_4$



Starting point	1	2	3	4
$LiFePO_4$ Error	0.01%	3.7%	0.2%	0.3%

The Importance of Measurement Accuracy

Correlation error for $LiFePO_4$



LFE
~3.7%
Error

LCO
< 0.5%
Error

LiFePO4
LiCoO2

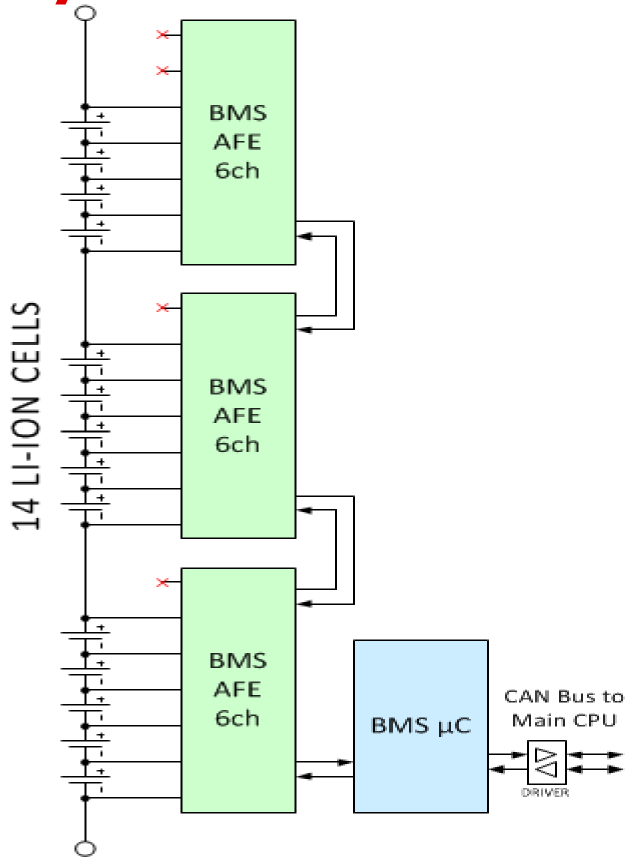
*correlation error scales proportionally. For example if the voltage measurement error is 5mV, maximal SOC error will be 3.7*5=18.5%

48V BMS IC Selection

- 48V Li-ion battery for high cycling performance, long life
- Depending on selected cell chemistry ~ 12-16 cells in series
- 14 is most common
- *But many Analog Front End (AFE) ICs in the market are 12 cell devices…*
  - *leaving 10 unused, but paid-for channels, and extra complexity!*
- The “just right” part would manage 12-16 cells as a single device
  - Simplification of design, smaller footprint, lower cost
  - Handles todays design and tomorrows
  - Accommodates wide range of chemistries from LFE to silicon
  - Scalable – stackable for other designs to maximize firmware reuse, minimize qualification costs

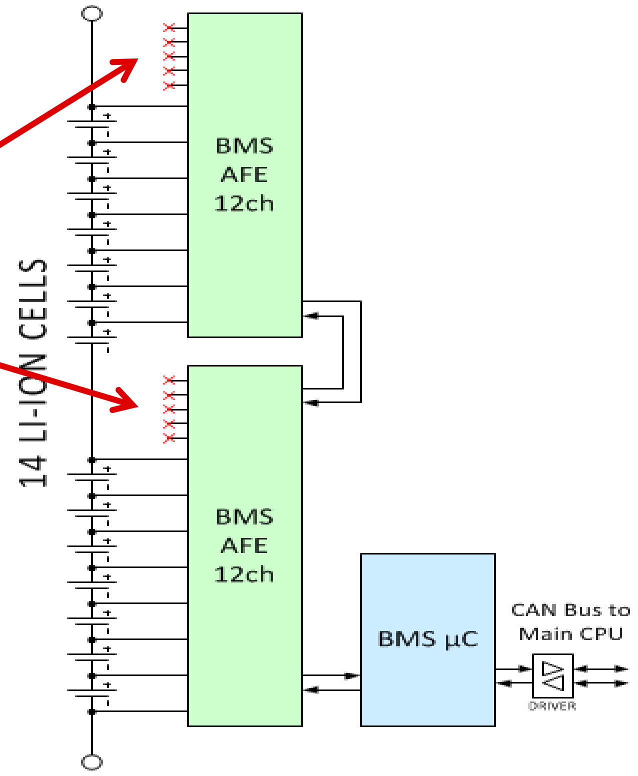
6 Cell / IC Analog Front End (AFE)

- 1st generation parts
- Typically implemented on single PCB
- May use micro + CAN bus per AFE in a distributed system
- Leaves **4** AFE channels unused…



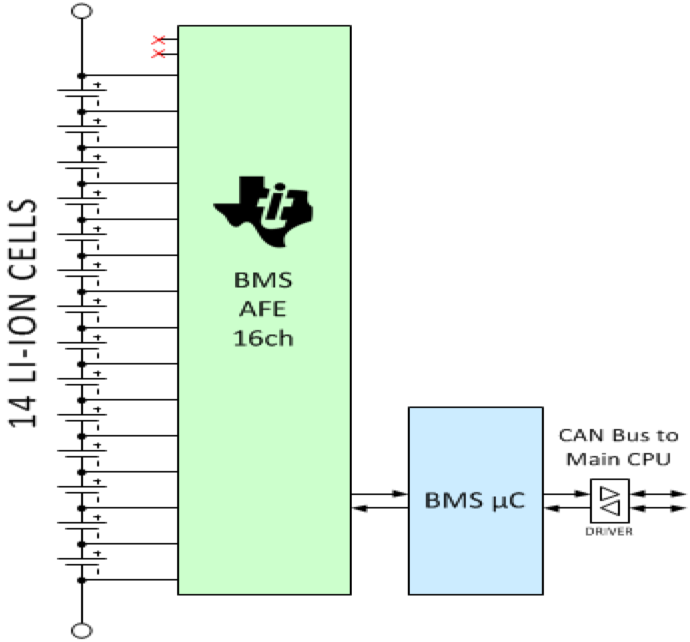
12 Cell / IC Analog Front End (AFE)

- 1st or 2nd generation parts
- Typically implemented on single PCB
- May use micro + CAN bus per AFE in a distributed system
- Leaves **10** AFE channels unused…
- Adds unnecessary expense and complexity

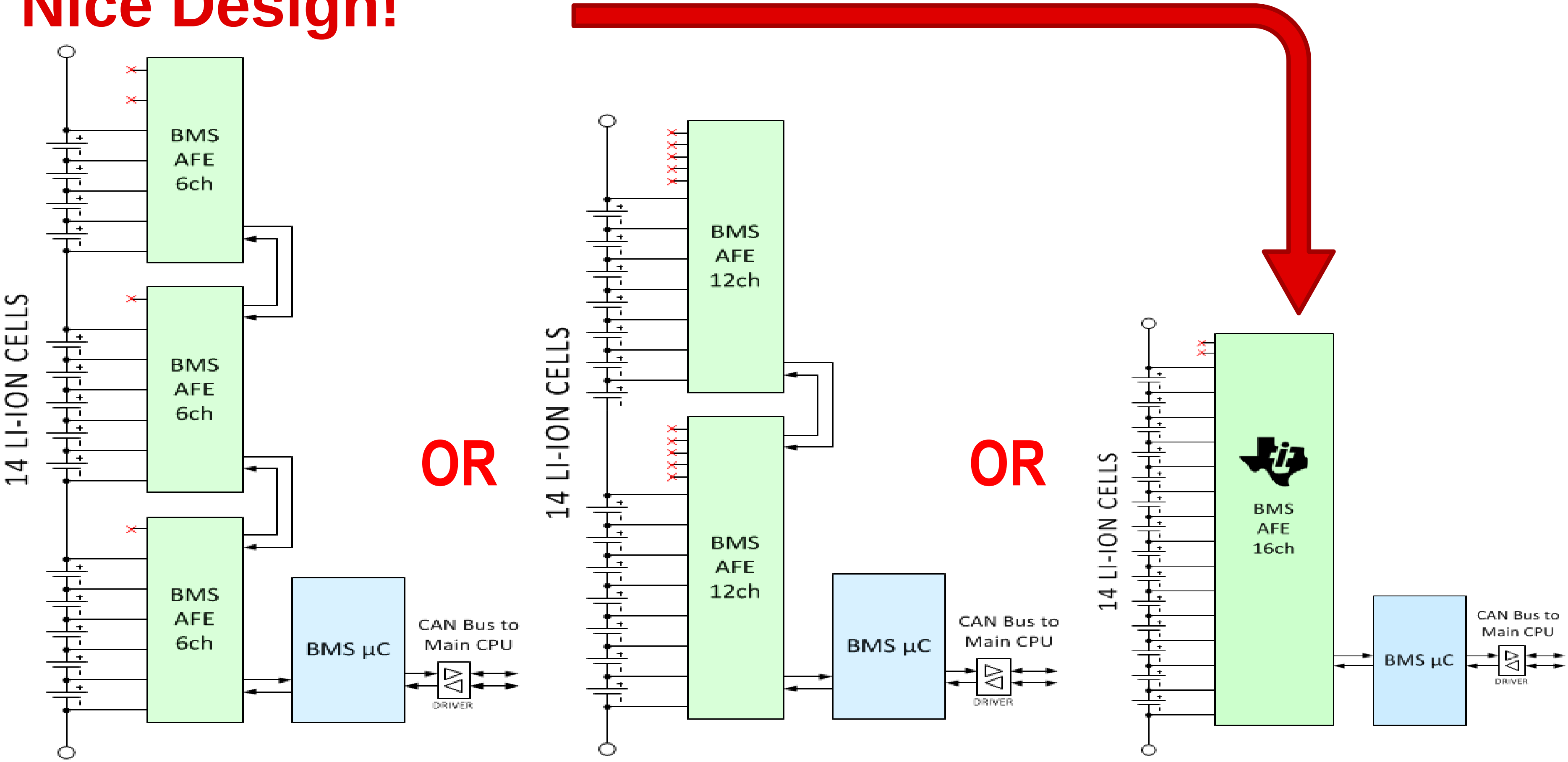


16 Cell / IC Analog Front End (AFE)

- 3rd generation parts
- Greatly simplified design
- 3+ fewer IC than 12ch devices
- 6+ fewer IC than 6ch devices
- ~1/2 (or less) the discrete components of the other designs
- Much smaller PCB possible
- No hot-plug issues
- Reduced EMC issues
- No communications problems
- Only 2 channels unused…

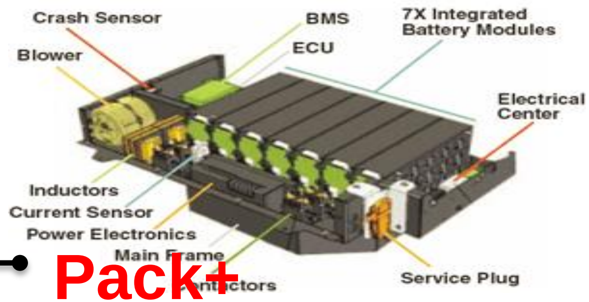


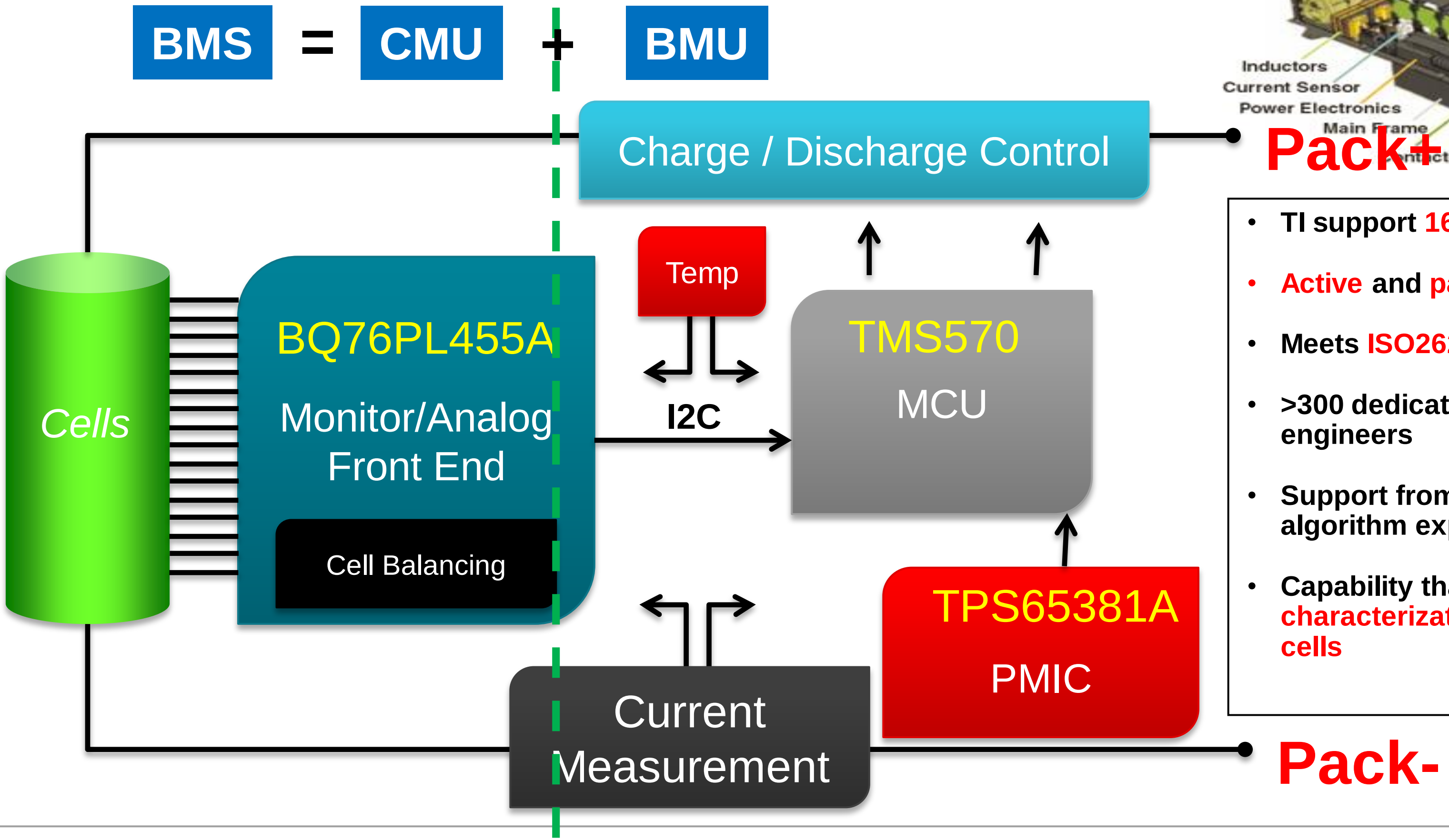
Nice Design!



14 LI-ION CELLS
BMS AFE 6ch
BMS AFE 6ch
BMS AFE 6ch
BMS µC
CAN Bus to Main CPU
DRIVER
OR
14 LI-ION CELLS
BMS AFE 12ch
BMS AFE 12ch
BMS µC
CAN Bus to Main CPU
DRIVER
OR
14 LI-ION CELLS
BMS AFE 16ch
BMS µC
CAN Bus to Main CPU
DRIVER

Why TI BMS for Automotive?





- TI support 16S solutions
- Active and passive cell balancing
- Meets ISO26262 for safety
- >300 dedicated battery design engineers
- Support from leading chemist and algorithm experts
- Capability that includes 100% characterization of all new battery cells

BQ76PL455A-Q1

EV/HEV 16-Cell Integrated Battery Monitor and Protector

Features

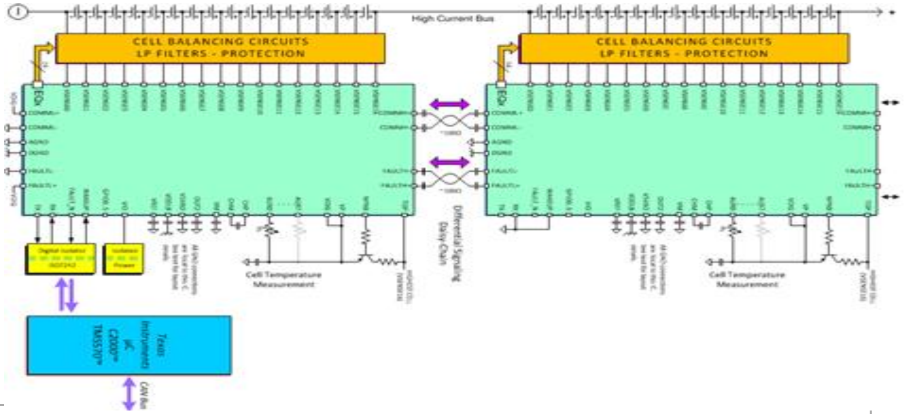
- Monitors **Up to 256-Series Cells** (16X16s)
- Operating voltage: 12V to 79.2V
- **Highly Accurate Monitoring** with Internal V_{ref}
  - Accuracy: **±3.5mV** @3.5V
  - All Cells Converted in ≈ 2.4 ms (nominal)
  - Eight Auxiliary Inputs
- Built-in **Secondary Monitors/Comparators**
  - Programmable **Overvoltage/Undervoltage**
  - Separate V_{ref} for Comparators
- One Mb/s **Stackable Differential Isolated UART**
- Designed for **Hot-Plug Performance**
- Passive Balancing with External N-FETs and Active Balancing with EMB1428Q/EMB1499Q
- Built-in Tests to Validate Defined Internal Functions, Open Wire Detection, etc.
- **AEC Q-100 Grade 2** w/ESD CDM Classif. of C3

Applications

- Electric and Hybrid Electric Vehicles (EV, HEV, PHEV, mild hybrid)
- 48 V Systems (Single-Chip Solution)
- Energy Storage (ESS) and UPS

Benefits

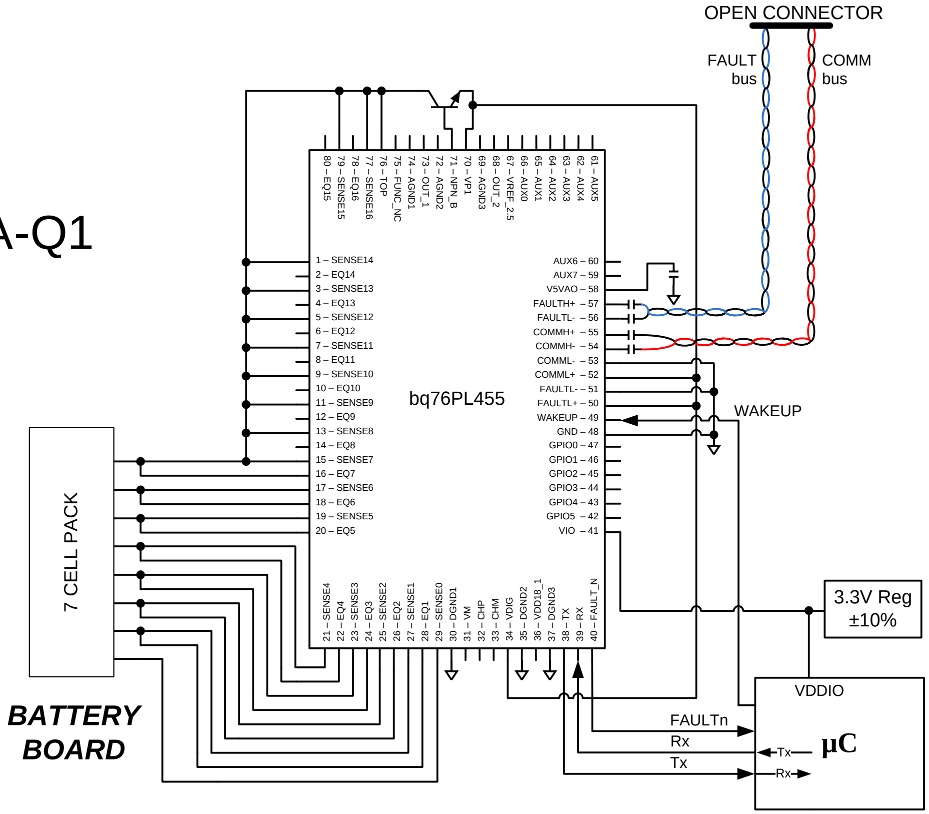
- Configurable Monitoring and Protection Features to Suit Multiple End-Applications
- Accurate State of Charge and State of Health
- High System Robustness
- Low BOM Count for Single/Multi-board Architectures
- Efficient Communications Performance
- Excellent EMI/EMC/BCI Performance
- Can Help Customer Achieve High Levels of Functional Safety (e.g. **ISO26262**)



Texas Instruments

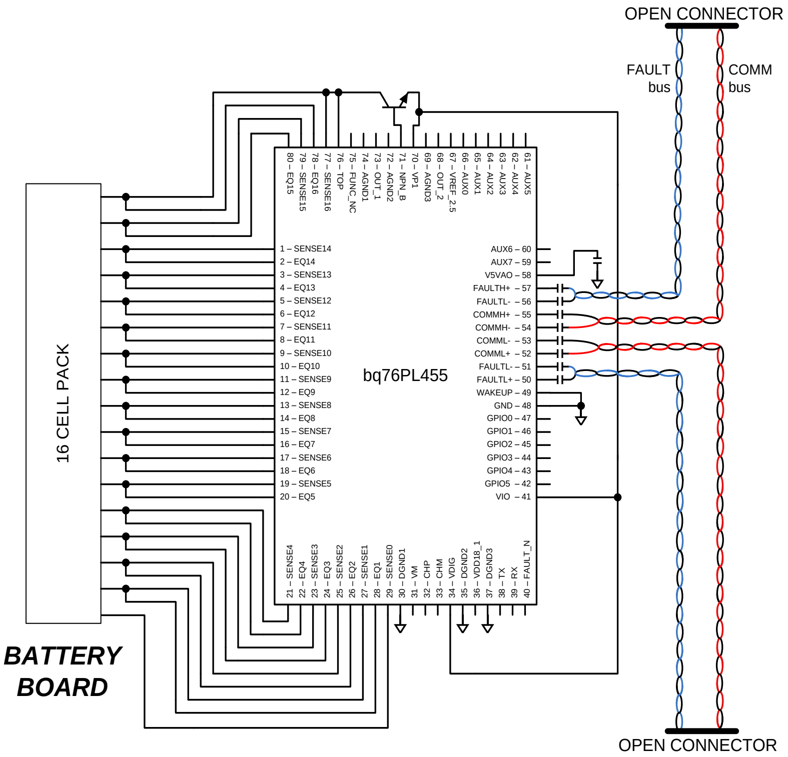
BQ76PL455A-Q1 Use Models

- Single device mode
  - 12V min to 16 cells supported
  - VP supplied from bq76PL455A-Q1 regulator
  - VIO supplied by MCU VDDIO



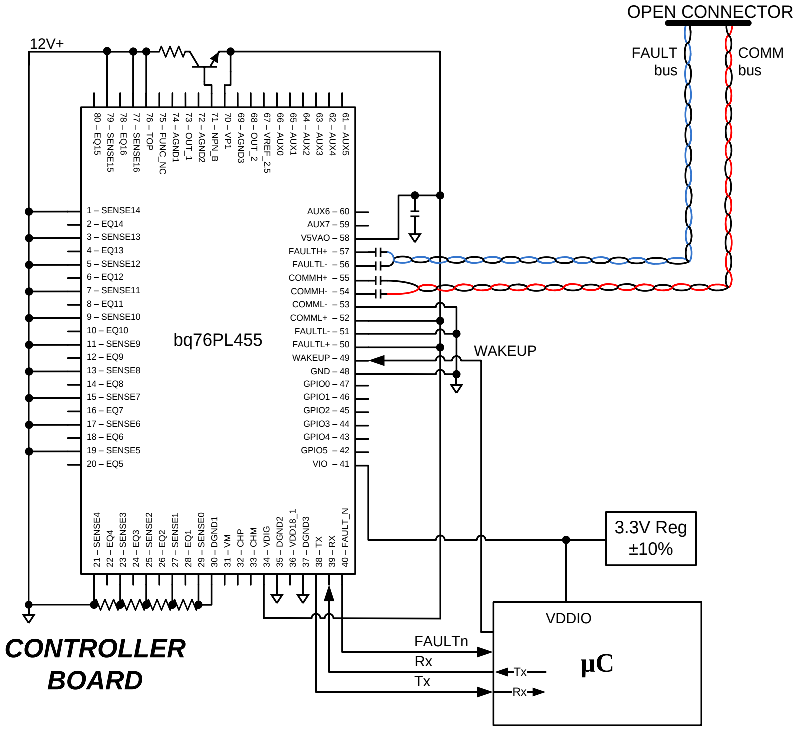
BQ76PL455A-Q1 Use Models

- Multiple device mode
  - Multi-device mode: multiple devices in “single” mode in parallel
  - Integrated Daisy-chain communication mode
  - VP supplied from bq76PL455A-Q1 regulator
  - VIO supplied by MCU VDDIO



BQ76PL455A-Q1 Use Models

- Bridge mode
  - bq76PL455A-Q1 used as a communications bridge from host micro-controller to one or more stacked devices in daisy-chain mode
  - VP supplied from bq76PL455A-Q1 regulator
  - VIO supplied by MCU VDDIO
  - In this example, TOP input = 12 – 20V
    - To support greater than 20V input, additional resistors will be required in the ladder below to ensure the max VSENSE input voltage on each input does not exceed 5.5V.



BQ76PL455A-Q1 UART Frame

- Single Device
  - DEV ADDR/ GRP ID holds Device Address
  - w/response, Data field holds Number of response bytes -1 (LSB)

Single Device Write CHANNELS register (0xFFFF0000 – 16 cell inputs only)	FRAME INIT[7:0]				DEV ADDR/ GRP ID	REG ADDR	DATA	CRC
	7	6:4	3	2:0				
Command	1	001	0	100	00	03	FFFF0000	51EE

Single Device Read CHANNELS register	FRAME INIT[7:0]				DEV ADDR/ GRP ID	REG ADDR	DATA	CRC
	7	6:4	3	2:0				
Command	1	010	0	010	01	03	03	68CD
Response	0	000	0	011			FFFF0000	4424

BQ76PL455A-Q1 UART Frame

- Group
  - DEV ADDR/ GRP ID holds group ID
  - w/response, Data field holds Address of highest responder (MSB), Number of response bytes -1 (LSB)

Group Write CHANNELS register (0xFFFF0000 – 16 cell inputs only)	FRAME INIT[7:0]				DEV ADDR/ GRP ID	REG ADDR	DATA	CRC
	7	6:4	3	2:0				
Command	1	011	0	100	01	03	FFFF0000	B1FE

Group Read CHANNELS register	FRAME INIT[7:0]				DEV ADDR/ GRP ID	REG ADDR	DATA	CRC
	7	6:4	3	2:0				
Command	1	010	0	010	01	03	0003	4824
Response	0	000	0	011			FFFF0000	4424

BQ76PL455A-Q1 UART Frame

- Broadcast
  - DEV ADDR/ GRP ID not used
  - w/response Data field holds Address of highest responder (MSB), Number of response bytes -1 (LSB)

Broadcast Write CHANNELS register (0xFFFF0000 – 16 cell inputs only)	FRAME INIT[7:0]				DEV ADDR/ GRP ID	REG ADDR	DATA	CRC
	7	6:4	3	2:0				
Command	1	111	0	001	N/A	03	FFFF0000	5105

Broadcast Read CHANNELS register	FRAME INIT[7:0]				DEV ADDR/ GRP ID	REG ADDR	DATA	CRC
	7	6:4	3	2:0				
Command	1	110	0	010	N/A	03	0103	87E9
Response	0	000	0	011			FFFF0000	4424
Response	0	000	0	011			FFFF0000	4424

BQ76PL455A-Q1 Configuration

- Typical configuration steps:
  - Interface activation
  - Device addressing
  - Channel configuration
  - Balancing configuration
  - Fault detection and notification
  - Clear faults
  - Configuration storage to non-volatile memory (only once at production)
- Configuration settings can be stored to on-board non-volatile memory
  - Configuration typically stored at pack assembly time
  - Configuration checked as part as “in-vehicle” testing

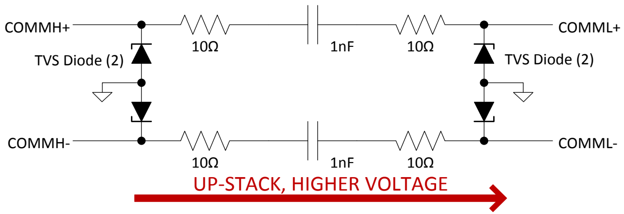
BQ76PL455A-Q1 Sampling

- Sample and send example

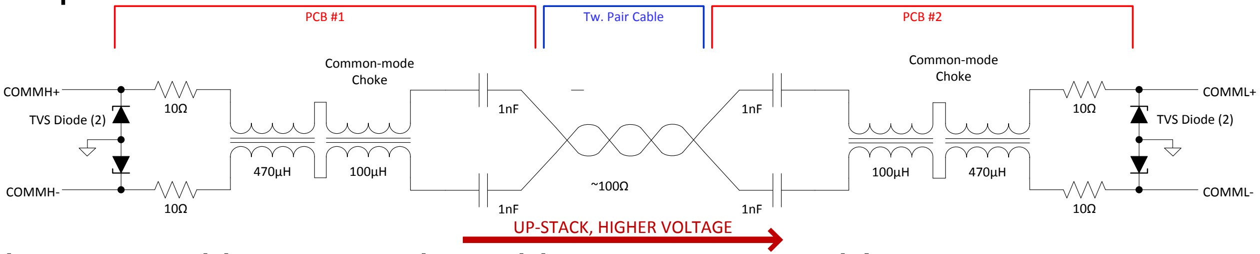
- Customer typically use sample and store method, do pack measurements during cell sample period, then read stored data later

BQ76PL455A-Q1 Communication

- External circuit
  - On same PCB



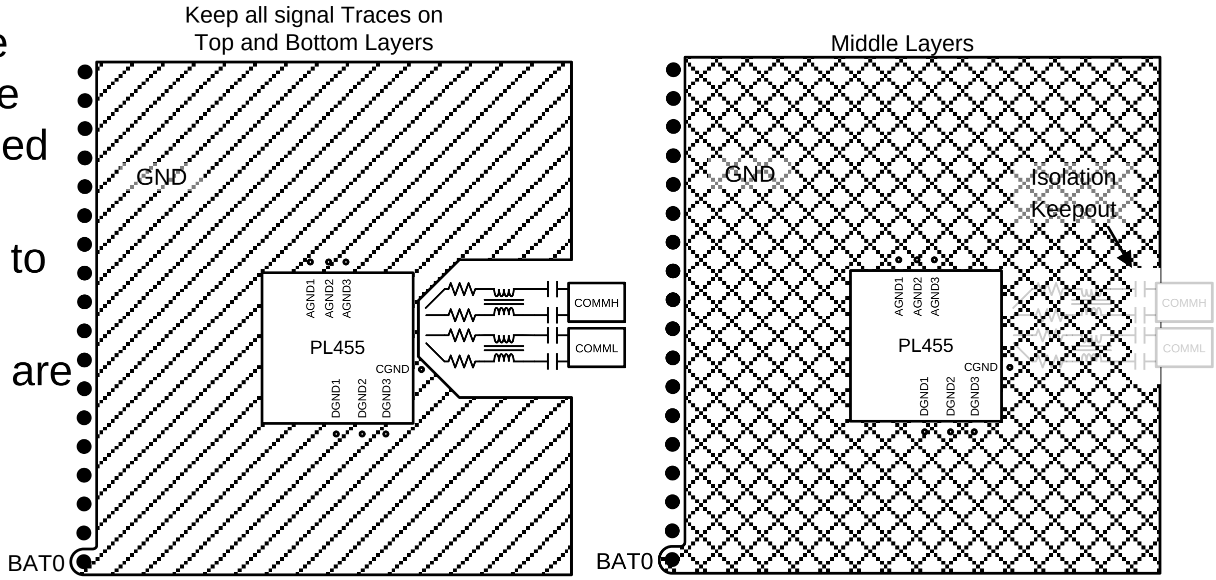
  - Via twisted pair cable



  - Values shown used in BCI testing with 16 ICs, 1m cable
  - Values can be adjusted for additional filtering in extreme conditions
    - 2 Common-Mode Chokes (100µH and 470µH) are recommended for best performance in noisy environments
    - Ultra-low capacitance TVS diodes should be selected

BQ76PL455A-Q1 Layout Considerations

- Layout
  - To ensure the best possible accuracy performance, it is recommended to follow some basic layout guidelines for the bq76PL455-Q1 to provide best EMI and BCI performance.
  - An unbroken ground plane layer as part of a 4 or more layer board is recommended
  - All AGND, DGND, CGND connections made directly to the plane.
  - The common GND planes are star connected directly to BAT0.



BQ76PL455A-Q1 Functional Safety

TÜVRheinland®
Precisely Right.

Summary

The evaluation came to the result that the battery monitoring IC BQ76PL455A-Q1 manufactured by Texas Instruments can be seen as qualified in accordance with ISO 26262-8, Clause 13.

Hence the IC can be used in safety related applications for "over voltage monitoring" and "over temperature monitoring" up to ASIL C according to ISO 26262.

Important pre-requisites:

- The fault line (FAULT_N) can only be used for safety related purposes if each single source that can trigger the FAULT_N signal (each single window comparator) is tested within the FTTI of the safety goal.

- Host controllers that are connected to the communication interface with the ability to change internal thresholds (e.g. for testing purposes) needs to be developed according to the ASIL of the safety goal.

- The component has to be integrated and used according to the requirements of the user´s documentation (including data sheet and safety manual).

BQ76PL455A-Q1 EV/HEV 16-Cell BMS with Passive Cell Balancing TIDA-00717

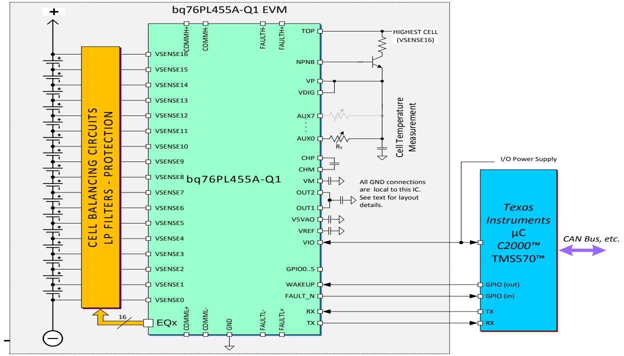
Features

- Stackable monitor and protector for use in large format Lithium-ion batteries that provides monitoring, balancing, and communications.
- Highly accurate monitoring of 16 Li-ion cells
- Integrated protector
- Engineered for High System Robustness
  - 1-Mb/s Stackable Isolated Differential-UART
- Cell balancing, diagnostics, and module to controller communication.
- Open Wire Detection

Benefits

- Helps systems to provide accurate state of charge and state of health calculation
- Up to 16 bq76PL455A-Q1 EVM modules can be stacked.
- Can withstand hot-plug
- Passes Bulk Current Injection (BCI) Test
- IC Helps Achieve High Levels of Functional Safety

System Level View



Thanks!

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265